Naval Ship Self-Defense Weapon Littoral Warfighting Performance Issues

Mr. Gil Y. Graff

Navy-supported combat in the 21st century will be driven by factors substantially different from Cold War era tactics and strategies. This article examines the implications of this new era on ship self-defense requirements; including the new operational environment, post-Cold War ship casualty thresholds, advanced and unconventional threats and tactics, as well as the requirements resulting from other warfighting missions.

With the end of the Cold War, concerns of ship defense have shifted from open-ocean conflict to conflict in the littoral. Whereas open-ocean conflict required superpower capability to launch multiple regiment bomber attacks against U.S. surface forces, conflict in the littoral brings U.S. surface ships within reach of land-based threats and short-range naval vessels. Though no longer faced with an enemy that is competitive in technology and in deployed assets, naval missions in the littoral present new and technologically difficult challenges.

Ship self-defense is the defense of one's own ship using assets organic to and under the direct control of the ship commander. This includes the defense against antiship missiles, bombs, ground-launched antiship weapons and weapons launched from other ships and submarines. This article will focus on one aspect of this mission, namely the defense against missiles, projectiles, and rockets.

Requirements to Operate in the Littoral

Naval operation in littoral waters is driven by naval missions as varied as sea control, mine clearance, presence, naval surface fire support, and even theater ballistic missile defense. In naval surface fire support, combatants must operate within the flyout range of both weapons and amphibious transport reach. The result is a desired combatant deployment range no greater than 46 km. Even large deck carriers must transit key straights and narrows such as the Strait of Hormuz, the Persian Gulf, the Adriatic Sea, the Taiwan Strait, and the Strait of Sicily, to name just a few. For the most part, it is the designated land attack combatants that must predictably close on hostile shores, and therefore ship defense requirements must be especially stringent for these ships.

OPERATIONAL ENVIRONMENT

The most profound difference between littoral and open-ocean environments is the difference between maritime and aviation traffic. The littoral is filled with both commercial and recreational vessels, as well as the nonhostile military vessels of allied and neutral navies. The presence of noncombatants expands the potential use of nontraditional platforms as platforms from which to attack U.S. forces.

The littoral environment presents a complex set of environments that is significantly different from the open-ocean environment. Key attributes of this environment include rapidly changing meteorology (including the presence of microclimates), complex oceanography, and unique land and sea clutter. Littoral oceanographic environments typically include a mix of shallow and deep water, which means a highly variable bottom composition that makes sonar detection of submarine and mines difficult. The acoustic environment can also be extremely variable, with large changes in sonar performance occurring within short distances. In addition, because the battlespace is geographically predefined, attacking weapons can exploit the solar corridor and use flight paths that use the sun as background to saturate or overload with solar glint. Adverse propagation in the littoral includes absorption effects caused by fog and atmospheric refraction effects.[1] Recent radar propagation measurements conducted off the Virginia coast have revealed subrefractive evaporative and surface-based ducting, with propagation varying as much as 50 dB over short intervals of height, range, and frequency, and over time intervals of less than an hour. The result is strong variation in the performance of current radars.[2] Even when propagation is conceptually favorable (as in superrefractive ducts), substantial increases in clutter due to Doppler processing ambiguities can result in paradoxically reduced radar performance. The magnitude of these propagation variations greatly overwhelms projected increases in sensor performance. Littoral environment propagation includes strong effects to infrared sensors. Whereas radar ducting is driven by relative humidity, electro-optic (EO) refractive propagation effects are driven by the air–sea temperature difference. Subrefractive EO propagation brings reduced detection ranges against low-flying missiles. However superrefractive propagation can result in the threat being presented against backgrounds containing strong solar glint. This source of IR clutter can extend over tens of degrees and result in regions where missile detection is not achievable.[3]

Finally, substantial populations of migrating and shore birds are seen in littoral waters. Over the eastern Mediterranean and southwestern Asia, migration patterns are shown in Figure 1 for warblers, thrushes, shrikes and gulls.[4] Similarly, bird migrations crisscross the Mediterranean, Adriatic, and Black Seas.

THREAT

In the current global economic competition, the export of sophisticated weaponry is seen as both a means to protect highly paid jobs and a substantial boost to the balance of trade. As a result, the lag between development (and nationally restricted

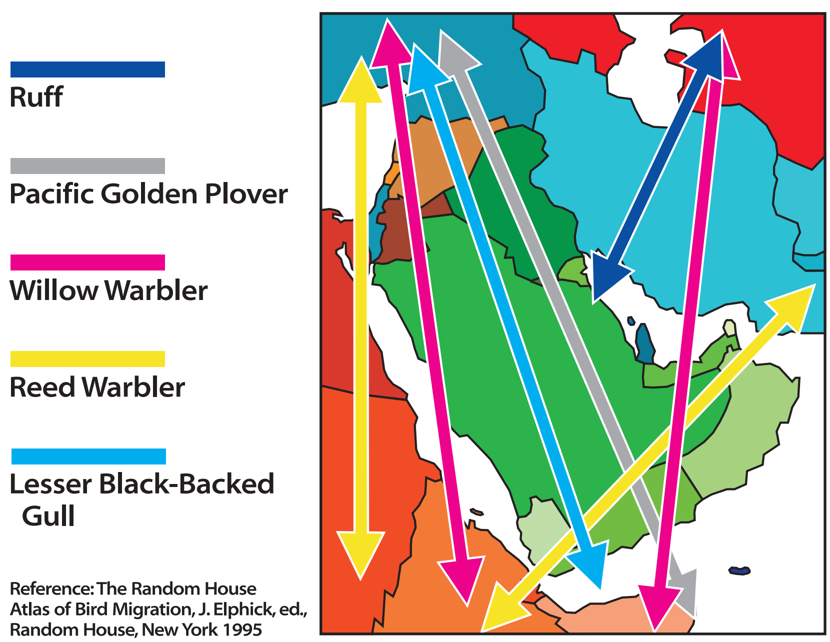

Figure 1—Bird Migration Routes of Southwestern Asia

deployment of advanced weapons) and export has been greatly reduced. Recent international weapon shows have featured the most recent weapons from the former Soviet Union, France, and China, among others.[5, 6] Weapons have even been offered for sale prior to completion of development.

The low-altitude cruise missile threat continues to evolve from its subsonic origins. Whereas these threats were originally subsonic and were designed to fly under ship radar coverage, recently available systems feature supersonic flight, preplanned evasive maneuvers, reduced observability, coordinated arrival times, multimode guidance, and emission control.

In addition to the evolving cruise missile, littoral operations bring the U.S. combatants within the range of a much varied set of weapons (shown in Figure 2) that include land-launched weapons, surface-launched weapons, and submarine-launched weapons. Where blue-water scenarios had regiments of large bombers, nuclear submarines, and heavy surface combatants, littoral situations confront us with small, fast patrol boats equipped with antiship missiles, and small diesel and midget submarines with cruise-missile launch capability.[7] Potential "low-tech" threats include fast recreational watercraft (boats and jet-skis) from which short-range weapons could be launched. While these weapons would not sink a combatant, these weapons could interfere with ship operations, distract from the pursuit of primary missions and, more significantly, damage ship sensors, thereby effectively removing the combatant from its mission. These weapons are subsonic but are launched from ranges of 0.5 km or less.

Perhaps the single greatest advantage that the surface defenses had in the open-ocean scenarios was the ability to remain hidden in the largely empty oceans. The littoral seas by contrast offer many opportunities for detecting large combatants, including via land-based ground sensors; land-based, short-range aircraft, and commercially available satellite imagery. The opportunity to hide has shifted to the offense in the littoral. Small vessels can hide among large numbers of commercial and noncombatant vessels. Similarly, small combat aircraft can count on the presence of numerous

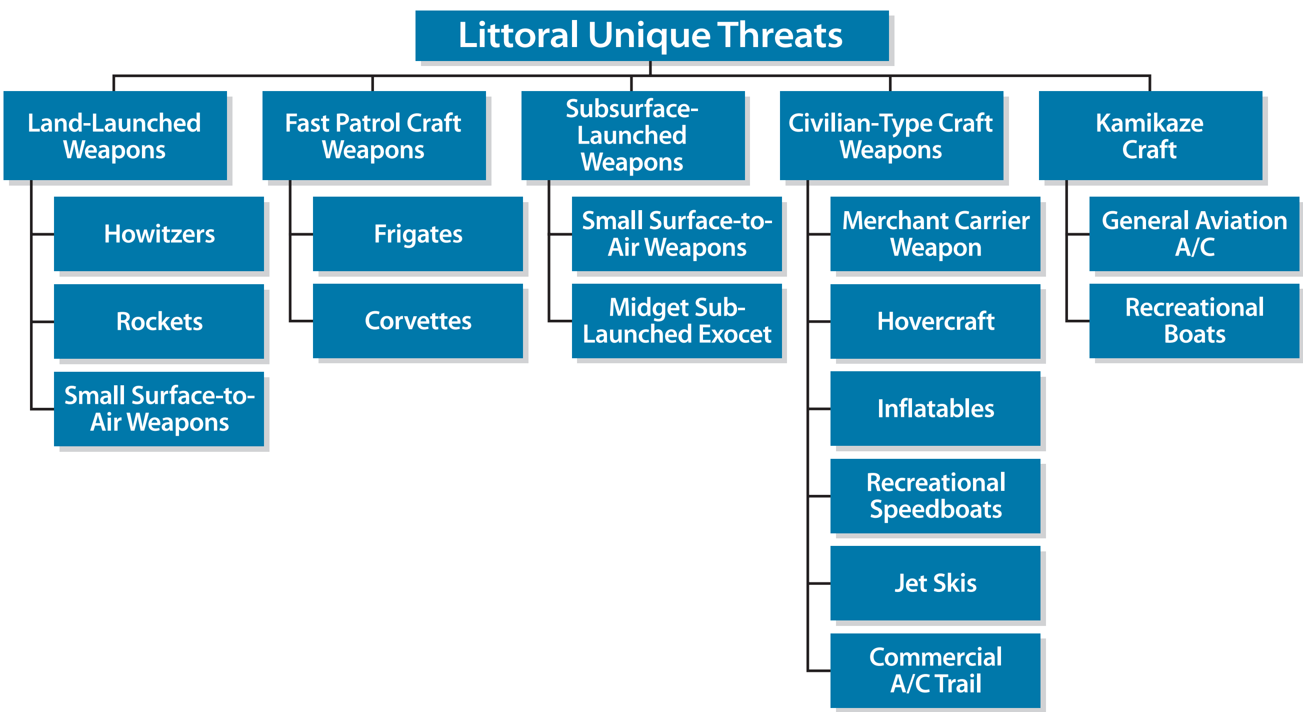

Figure 2—Littoral Zone Unique Ship Self-Defense Threats

commercial aircraft and can, when the opportunity presents, hide itself in proximity to the commercial aircraft. Land-launched unguided artillery or inertial guided weapons will also threaten when U.S. forces must traverse choke points, safeguard slowly moving vessels, or transit minefields.

SELF-DEFENSE WEAPON SYSTEM ELEMENTS

A ship self-defense weapon system is functionally structured into Detect, Control, and Engage functions. This functional formulation was initially formulated in the development of the Aegis combat system. Defense starts with detection of objects, and the defense functional sequence continues with classification and threat evaluation, track formation, weapon selection, weapon readying, weapon launch, inflight weapon control and weapon performance/kill assessment. These functional elements occur in a self-defense sequence that is classically shown in a timeline, as shown in Figure 3.

Self-defense weapons are characterized as either terminal defense or nominal self-defense weapons, depending on the effective intercept ranges, shown in Figure 4. Terminal defense systems typically are effective inside of one mile. In order to achieve these close-in kills of even large cruise missiles, catastrophic damage of the threat must occur in which the threat is broken into small structural pieces, either through detonation of onboard energetic elements or through structural defeat of the airframe. In either case, direct hits with large fragments are required. Nominal self-defense weapons defeat the threats at longer ranges, typically two to five miles away. At these ranges, catastrophic kill is not absolutely required. However, mission kills—in which the threat no longer functions sufficiently to achieve ship damage—leaves no time for kill assessment. Mission kill further limits the inner defense boundary and thereby indirectly limits the capacity to engage a series of threats.

The unique character of the low-altitude threat is that the functional sequence starts when the threat is inside the surface horizon. This aspect is further exploited by supersonic threats, which reduce the time available to achieve intercepts, resulting in a battlespace that can currently be filled with only a

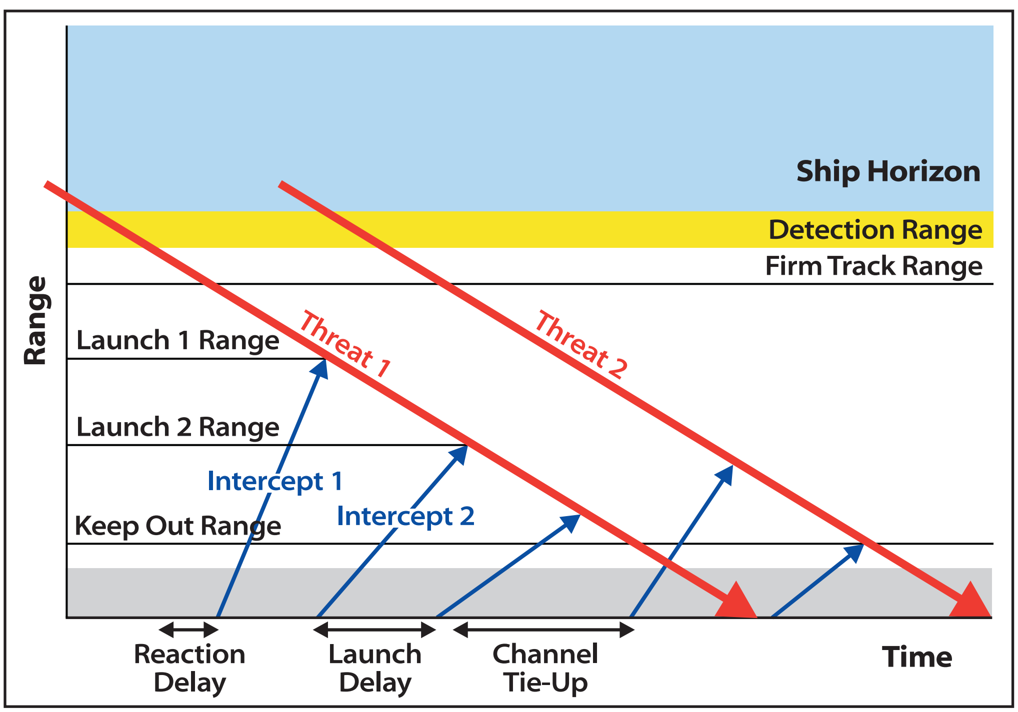

Figure 3—Ship Self-Defense Notional Timeline Against Low-Altitude Cruise Missiles

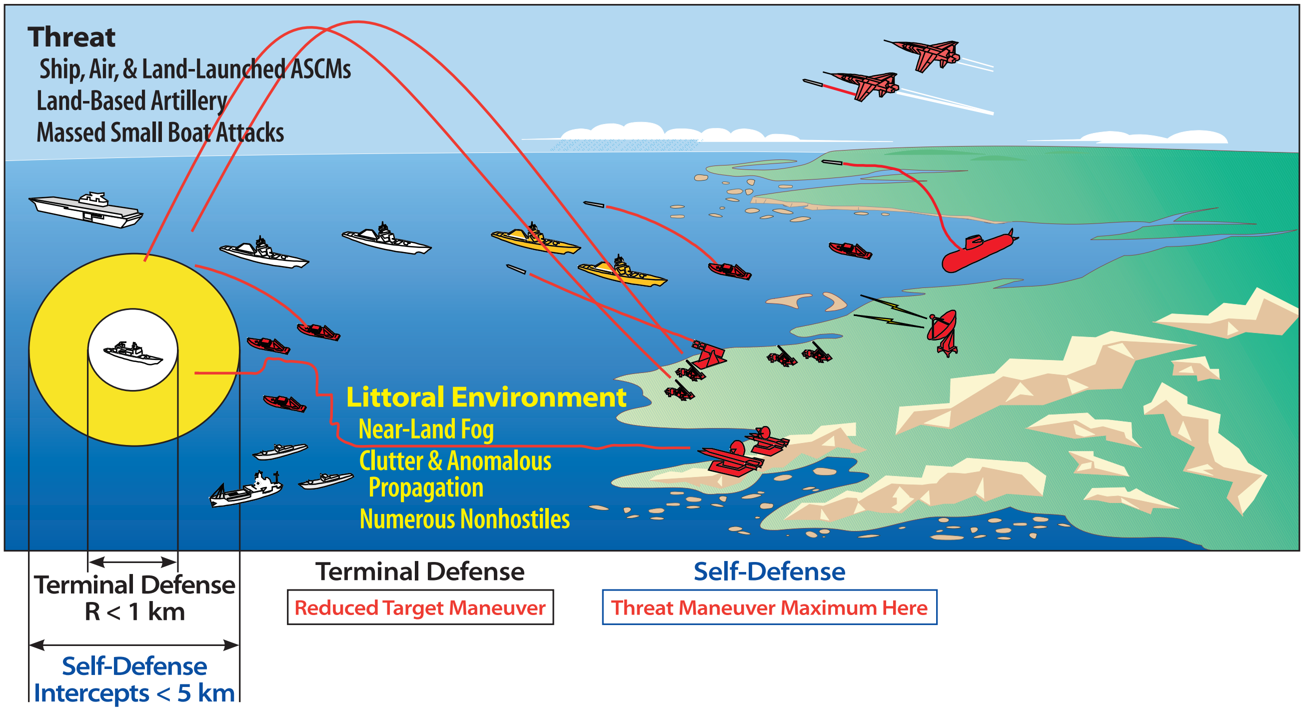

Figure 4—Ship Self-Defense Archetypes in the Littoral Environment

small number of engagements per threat. The result is a severe challenge to detection, control, and engagement systems. The detection challenge in the classic open-ocean, low-altitude cruise missile defense problem is the presence of a deep propagation null near the surface horizon, in which radar propagation has been shown to approximately inversely vary with range to the 11th power. This contrasts strongly with 4th power free space propagation. This problem is greatly amplified by low-observable weapons design. The low-altitude cruise missile detection problem was featured in the September 1992 issue of the *Naval Surface Warfare Center, Dahlgren Division (NSWCDD) Technical Digest*.

The littoral warfighting dimension of this problem is the further challenge of detecting threats in the presence of the adverse propagation discussed above. The classic ship self-defense control problem is the reduction of weapon system reaction delays sufficient to engage the supersonic, low-flying cruise missile. The littoral warfighting weapon control challenge consists of both the need to rapidly assess nontraditional weapon platforms and weapons as hostile threats, and the need to control the large numbers of weapons required to defeat multiple threats launched from very short range. Similarly, the classical low-altitude, ship self-defense challenge is the defeat of the supersonic, maneuvering, low-altitude cruise missile, as exemplified by the SSN-22 Sunburn and ANS missiles. Weapon design to defeat the low-altitude cruise missile was featured in the September 1994 issue of the *NSWCDD Technical Digest*. The additional weapon challenge presented by the littoral environment is the defeat of small, subsonic weapons launched from ranges less than one mile, and the disabling and destruction of high-speed small craft, whose hostile intent is discovered only at short range.

TOP-LEVEL WEAPON SYSTEM PERFORMANCE REQUIREMENTS

Engineering and development of weapon solutions begins with the specification of top-level, weapon-system performance requirements. During the development of the Aegis combat system, these requirements were called the cornerstones. Currently, the top-level performance requirements are the specified CAPSTONE requirements for each mission area. Whatever the name, the top-level specification represents goals directly associated with achieving a warfighting objective. In the case of ship defense, the overall defense objective is mission protection, namely the ability to conduct primary warfighting missions despite the presence and use of antiship weapons. These ship defense requirements are specified by OPNAV N865. The requirements balance the need for a capable ship defense against affordability. In so doing, the requirements differentiate among ship classes, for which separate requirements are based on threat projections for each class. These requirements specify, for each ship class, the number of threats and the threat arrival rate, and the required probability of mission survival. A simplified, top-down process to drive ship defense weapon development towards the top-level goals is shown in Figure 5. While a top-down development strategy is mandatory, the actual process implementation is not unique due to the numerous complex interactions among requirements of all levels. The process is further driven when there is the cost-driven need to satisfy top-level objectives within the constraints of a modest evolution of current weapons.

To satisfy the ship self-defense warfighting objective, ship defense performance shall neither limit the operational environments, nor limit the ship resources needed by the primary warfighting missions. Thus, ship defenses shall prevent loss of ship function and loss of life. With the narrow engagement windows associated with self-defense, this requirement demands both all-aspect weapon firing arcs and successful weapon performance.

Weapon coverage is addressed in the Ship Fit top-level objective, in which either separate small weapon stations or vertical launch is used to achieve all-aspect weapon coverage. But how will this be

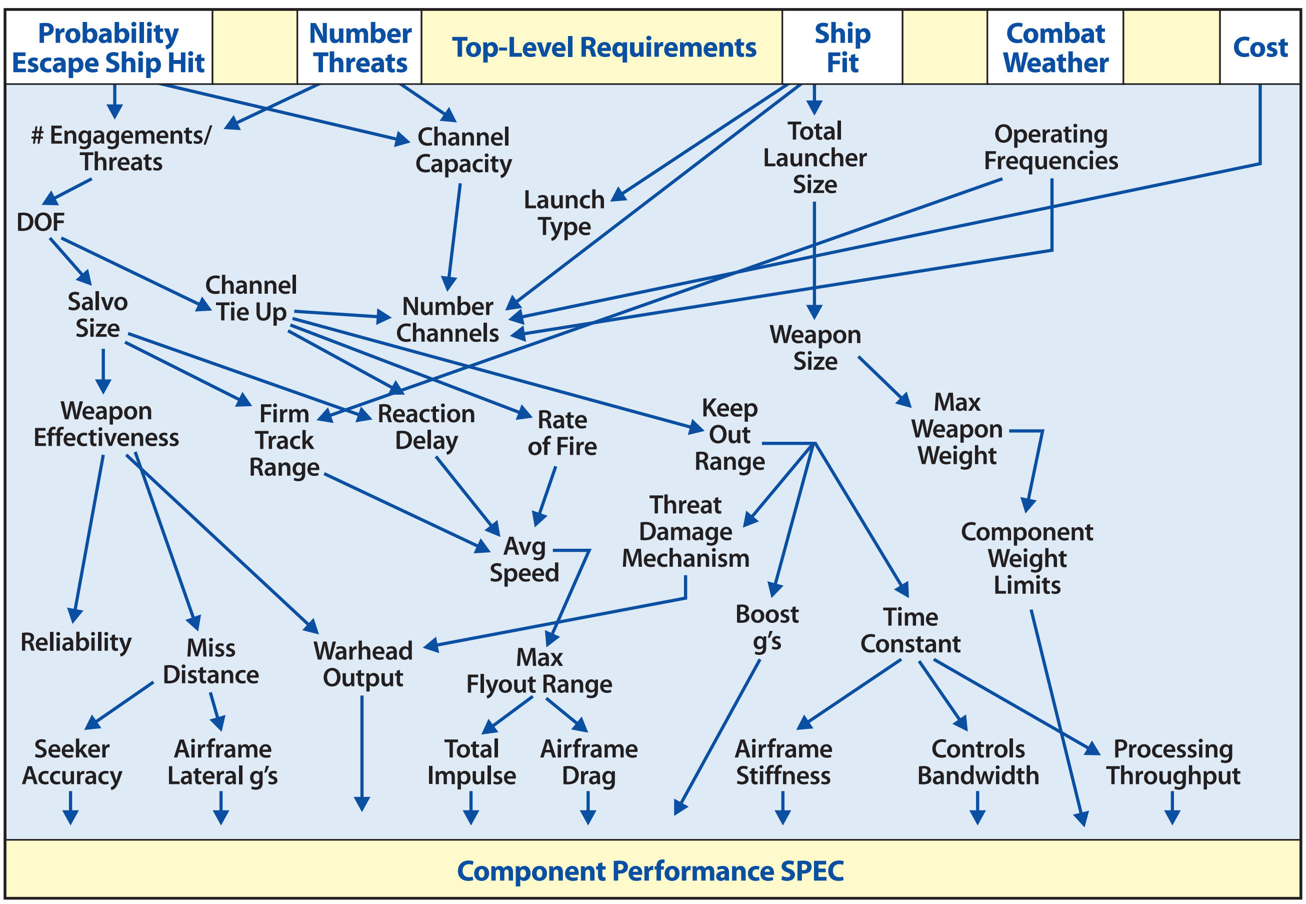

Figure 5—Requirements Driven Self-Defense Weapon Design Process

achieved when faced with large numbers of threats? Ship defense performance limitations shall not limit the combat conditions under which primary warfighting missions are conducted. This top-level requirement is called Combat Weather in the figure and requires operation in adverse weather environments to the extent that the final top-level objective can be satisfied—namely, affordability.

Weapon system performance is covered by the requirement that is mathematically formulated as the requirement to achieve a specified *probability of raid annihilation* (PRA). One issue is the PRA value that self-defense weapons should achieve. Given the remaining ill feelings left over from the Vietnam war, it is clear that when in combat with Third World countries, even small numbers of casualties may result in demands for withdrawal. In Desert Storm, an entire amphibious operation was cancelled over fears of mines and ground-based antiship missiles. However, what should the PRA be against weapons incapable of causing multiple casualties? The factors governing PRA are the probability of successful one-on-one engagement, the number of weapons employed against each threat (i.e., salvo size), the number of independent engagement opportunities, the weapon magazine capacity, and the weapon channel capacity. The latter parameter defines system performance against simultaneous or near-simultaneous threat raids. The relation between PRA, number of threats, and weapon effectiveness (P_K) is shown in Figure 6 for a salvo size of two. If PRA is required to be 0.9, weapon P_K must exceed 0.9. The individual weapon effectiveness requirement can be reduced to 0.7 if the salvo size is increased to four; however, in this case, large weapon magazines are required. Because these short-range weapons and platforms are so inexpensive, an enemy will be tempted to deploy large numbers of armed small craft. The sensitivity of escaping hit by large numbers of threats is shown in Figure 7, in which it is seen that the PRA drops sharply as the number of threats increase above four. This figure presents the case of a system capable of a single layer of defense with unlimited channel capacity and assumes a sufficiently large weapon magazine. Even so, in order to reach minimally acceptable values of escaping hit, salvo sizes of three and greater are required. This implies a magazine capacity exceeding 30 rounds per attack. Prudence dictates that defensive magazines be sized to counter several attacks prior to requiring at-sea replenishment. Another factor affecting magazine requirements is the need for all-aspect coverage, which can

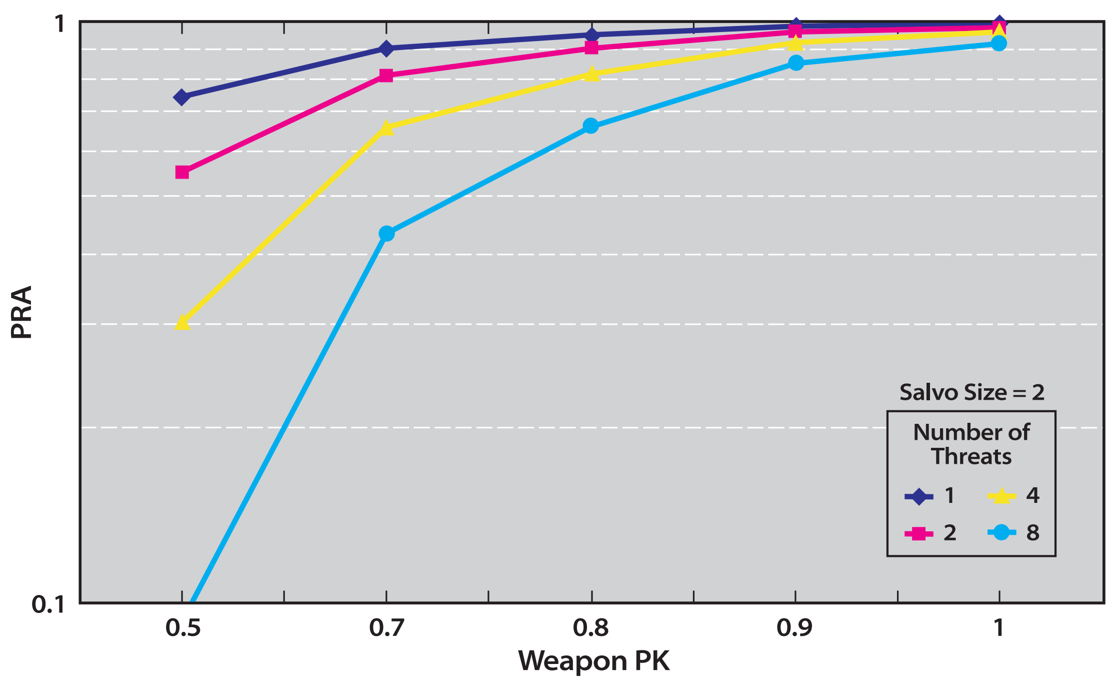

Figure 6—Probability of Raid Annihilation (PRA)

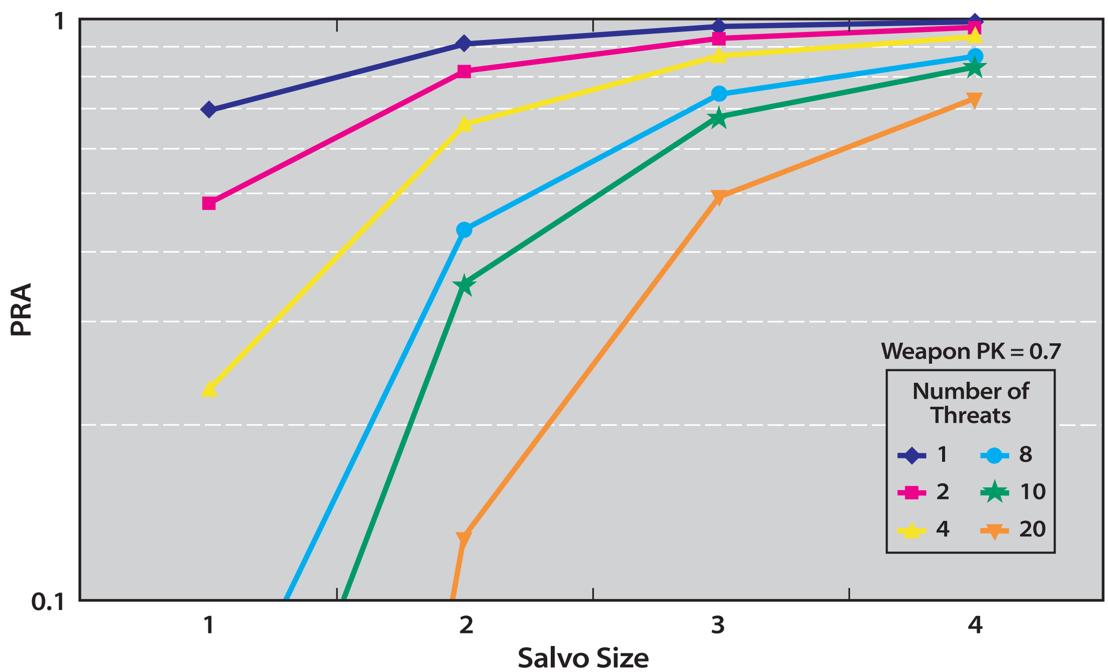

Figure 7—Probability of Escaping Hit vs. Salvo Size

be achieved either by multiple weapon mounts placed around the ship or with vertically launched weapons. Even with vertically launched weapons, however, the magazine of weapons should have a capacity of approximately 100 guided weapons.

It should be clear by now that letting the enemy have the first shot results in exceedingly difficult requirements. Examining the timeline reveals a further difficulty that this problem presents. Figure 8 plots the achievable intercept range as a function of weapon reaction time and threat launch range. This figure assumes a missile defense. It is clear that weapon reaction times cannot exceed 1 s. Further, when missile average boost acceleration is less than 50 g, it becomes impossible to achieve intercepts against weapons launched from inside 250 m. Similarly, a gun-launched guided projectile can achieve intercepts against threats launched from inside 250 m but reaction times of 1 s are still required. To handle multiple threats at such short ranges would require rates of fire equal or greater than the product of the number of near simultaneous threats and the one-on-one engagement rate of fire. Thus, to handle large numbers of threats, rates of fire will easily exceed 100 rounds a second.

WEAPON ALTERNATIVES

A more reasonable defense alternative is accomplished by using a combination of a counterplatform and a counterweapon system. The mission of a counterplatform is to either dissuade or destroy the small weapon launch platform before the platform can close within weapon flyout range. This weapon should be capable of intercepts at 500 m and greater. Because of the less demanding timelines associated with the counterplatform weapon, the burden of engaging large numbers of threats should be assigned to the counterplatform weapon. Counterplatform weapon alternatives include projectiles and missiles. Magazine requirements for the counterplatform should still be large. Thus, cost and weapon size become major drivers. A low-cost weapon will consist of command midcourse guidance using low-cost, inertial sensor technology currently under development, one probably using impulse control. Because of the need to engage large numbers of platforms, it is unlikely that these weapon objectives can be satisfied with an unguided weapon.

The counterweapon system must be ready to shoot within a reaction time of 1 s. Intercept ranges for

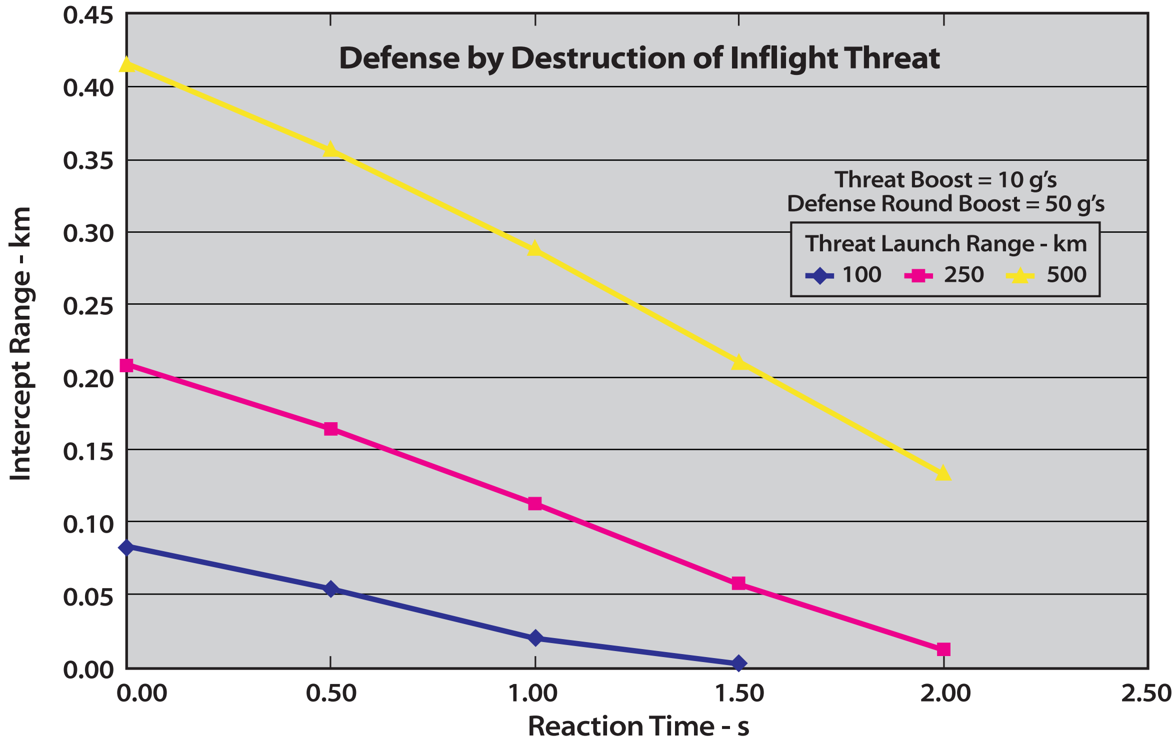

Figure 8—Ship Self-Defense Timeline Unconventional Threat

this weapon should reach 500 m. Threat loading requirements can be reduced to a small number of simultaneous threats. However, average boost accelerations must exceed 50 g, and this probably rules out vertical weapon launch. The weapon firing rate for the counterweapon system should exceed 10 shots per second. Weapon candidates for the counterweapon system include guided projectiles, missiles, high-rate-of-fire unguided gun weapons, and directed energy.

CONCLUSIONS

In summary, the need to conduct naval operations in littoral seas results in a complex new set of ship defense challenges. These challenges include adverse propagation environments and defeat of multiple small weapons launched from very short range.

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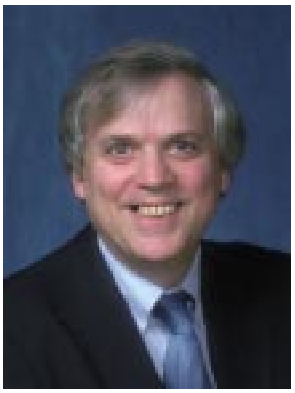

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